INITIAL L2C MULTIPATH AND NOISE PERFORMANCE ANALYSIS FROM REAL DATA[1]

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RESUMO

A modernização do Sistema de Posicionamento Global tornou-se uma realidade com o lançamento dos primeiros satélites modernos do bloco IIR-M. O novo sinal L2C tem potencial para fornecer informações adicionais além do que ocorre com os sinais existentes, tais como em ambientes com obstruções (áreas urbanas, cânions e floretas). Obviamente, surgem alguns questionamentos. Qual a evolução em termos de desempenho, facilidades de uso e qualidade da posição que este novo sinal traz para usuários civis? Haverá melhoras em relação a velhos desafios, como erro ionosférico e multicaminho? Com o lançamento dos primeiros satélites transmitindo o novo sinal L2C a possibilidade de uma análise do comportamento deste sinal sob multicaminho e ruído, e fazendo uso de observações reais, tornou-se uma realidade. Duplas-diferenças residuais de multicaminho e ruído foram extraídas de medidas de código e fase do L2C, bem como a partir do código C/A na portadora L1, para análises comparativas. A repetibilidade diária destes sinais foi investigada, objetivando extrair e separar o multicaminho e o ruído. Resultados preliminares confirmam valores de multicaminho ligeiramente menores no sinal L2C.

Palavras-chave:

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ABSTRACT

The modernization of the Global Positioning System has become already a reality with the launching of the first modern satellites. The new L2C signal has potential to provide additional information beyond the existing signals such as in environments with obstructions (urban areas, canyons, and forests). Obviously, questions arise. What is the evolution in terms of performance, user facilities and positional quality that this new signal will bring to civilian users? Will there be improvements over the old challenges experienced by the legacy signal, such as the ionospheric error and multipath? With the launch of the first satellites broadcasting the new L2C signal the possibility for an analysis of the behaviour of this signal under multipath and noise making use of actual observations became a reality. Multipath and noise double-difference residuals were extracted from L2C phase and code pseudorange, as well as from the existing C/A code in the L1 carrier for comparative analysis. The daily repeatability of these signals has been investigated aiming to extract and to separate the multipath and noise. Preliminary results confirm slightly smaller multipath values in the L2C signal.

Keywords:

1. INTRODUCTION

Legacy GPS receivers still struggle to track the satellite signals in challenging environments such as under heavy foliage, urban areas and canyons, and indoor applications. In these cases the modernization of the GPS signals heralds great news to users, especially the new civil L2C signal. This new signal is modulated in the L2 carrier and has a 2.046 MHz null-to-null bandwidth power spectrum, i.e., similar to the C/A code modulated in the L1 carrier. The new L2C signal is designed to offer advantages with respect to the C/A code only. One of them is the possibility to cancel or to minimize the ionospheric induced error which is feasible from a combination with the existing L1C/A-code-based signal and a better acquisition of weak signals that facilitates indoor applications, such as the use of GPS (card) receivers in cell phones. It is possible to imagine the impact of L2C single-frequency receivers in the future when the L2C constellation is completed, by 2013. Until then, the problem of the large ionospheric error on the L2C signal must be solved, because it is 65% worst than that of C/A. In the next years there will be a push in the market towards L1/L2C receivers (Chastellain et. al., 2005). Improvements in ionospheric correction, which is a large limiting factor to civil receiver performance, will also be addressed with the new L5 carrier frequency. There is a big expectation on the benefits this modernization will bring for anybody who, in various ways, utilize the system. We foresee interesting applications of this signal in cell phones, for example. The multipath problem seems to still deserve a great attention since it remains the biggest challenge to reach the highest accuracy mainly in applications where the scenario changes in terms of geometry among the receiver antenna, satellites and reflectors. Efforts are made in receiver processing signal improvement, including modifications of techniques already used to treat the existing signals. Some of them are designed from synthetic signals (i.e., generated by hardware or software simulator) and therefore with theoretical results but with important conceptual contributions. With the launch of the first satellites broadcasting the new L2C signal it became possible an analysis of the behaviour of this signal under real multipath and noise making use of actual observations. By the time the analysis presented in this paper was carried out there were 3 (modernized) Block IIR-M GPS satellites orbiting the Earth transmitting the L2C signal besides the C/A and P(Y) codes in the L1 and L2 carriers. They were satellites PRN 12, 17 and 31. (Since then, other satellites have been launched: PRN 15, 29 and 07) Particularly important was the launching of satellite PRN 12 in 2006, which provided for the first time an overlapping of two L2C signals, in alternate periods, with PRN 17 and 31. These two satellites, launched earlier did not provide simultaneous observations. This fact has created the opportunity of setting up an experiment making use of combinations involving the new L2C signal. Before that analysis between L2C signal (from PRN 17 and 31 satellites) and C/A code on L1 carrier (from the current satellites), for example, similar experiment was only possible by using simulated data. The current work presents an analysis of this new signal focusing on multipath and noise. Data was collected in consecutive days over a very short baseline using two ProPak-3 NovAtel receivers equipped with a 20 MHz, voltage-controlled, temperature compensated crystal oscillator and the NovAtel GPS-702GG antenna model. Multipath and noise double-difference residuals were extracted from L2C phase and code pseudorange, as well as from the existing C/A code in the L1 carrier for comparative analysis. Preliminary results confirm slightly smaller multipath values in the L2C signal.

2. L2C SIGNAL STRUCTURE AND CHARACTERISTICS

The L2C is a chip-by-chip time division multiplexed (TDM) dual code, i.e., it is formed by the multiplexing of two PRN codes, a moderate-length code (CM) and a long code (CL). It means that the two codes are arranged such that a chip of the CM code is transmitted followed by a chip of the CL code. The CM code has a length of 10230 chips which is equivalent to a 20 ms period and it is initially modulated with 25 Hz message data and after with the same frequency of that in the L1 carrier, i.e., 50 Hz. The one-half rate initial data modulation makes possible the L2C demodulation in challenging environments. The CL code has a length of 767250 chips which is equivalent to 1.5 seconds. At the receiver level the CM and CL codes are obtained from a local generator, carrier tracking, code tracking and navigation message decoding with some modifications to the way it is done to the C/A code in the L1 carrier because of the different signal structure (Misra & Enge, 2006). It is from the CL code that we expect a better multipath attenuation capacity and interference resistance because it possesses better correlation properties than the L1 C/A code. This happens because this code does not have navigation data making possible long integration periods, which provides the CM and CL signal combination an important characteristic in obstructed signal places. This is a coherent integration to the carrier tracking and a coherent and non-coherent combination to the code tracking. From the CM code a better signal initial acquisition is expected. It is an important limitation of the fact that the L2 carrier does not have institutional protection against radio-frequency interferences unlike the L1 carrier. Apart from this difference both CM and CL codes have the same 511.5 MHz code clock rate each. Therefore the L2C signal has the same code clock rate than the L1 C/A code, i.e., 1,023 MHz, but they are different in other aspects. For example, since both CM and CL are much longer than the 1,023 C/A code length the maximum lines in the L2C power spectrum are far lower than the maximum lines in the C/A code power spectrum, which increases the robustness in the presence of narrowband interference. The minimum specified received L2C signal power level for signals broadcast from the Block IIR-M and Block IIF satellites is -160 dBW (Kaplan and Hegarty, 2006). As far as L2C, the received power in the receiver antenna is -133dBm, i.e., 2.3dB lower than the L1 and it still can be helped by external sources as “assisted GPS”. In terms of the dual-frequency users the most important topic is to eliminate the need for the semi-codeless tracking technique currently used to acquire the L2 measurements because it has no data on one of the two codes, which means a 3 dB improvement to tracking threshold performance. In terms of the single-frequency users the main objective is to be a better option that the C/A code in the L1 carrier which have lower cross-correlation performance (21 dB) while the worst case cross-correlation to L2C is 45 dB which make possible to read navigation message even under bad signal conditions. In Fontana et al. (2001), you can see more theoretical details about the L2C code tracking accuracy and simulated results. In a nutshell, the L2C has better performance to cross-correlation threshold tracking and data recovery, low consumed power and flexibility in design of radio-frequency (RF) filters. The exception is the higher ionospheric refraction error. The follow expressions show mathematically the model of the received L2C signal (Ziedan, 2005):

$$
\begin{aligned}
r_{L2C}\left(t_{i_l}\right) = A.&\left\{\begin{matrix} d\left(t_{i_l}, f_d\right) C_{M0}. \\ .\left(t_{i_l}, f_d\right) + C_{0L}\left(t_{i_l}, f_d\right) \end{matrix}\right\}. \\
.\cos&\left(\begin{matrix} \theta_0 + \theta_{n_{i_l}} + 2\pi.\left(f_{IF} + f_{d_0}\right).t_{i_l} \\ + \pi.\alpha.t_{i\,l}^2 \end{matrix}\right) \\
+ n_{i_l}&
\end{aligned}
\qquad (1)
$$

where t_{i_l}, $f_d = \left(t_{i_l} - \tau_{e_i}\right)\left(1 + \frac{f_{d_0} + \alpha t_{i_l}/2}{f_{L2}}\right) \cdot \tau_{e_i}$ is the code delay error at the i^{th} intervals, θ_0 and f_{d_0} are the phase and Doppler shift at the start of the tracking, α is the Doppler rate, f_{L2} is the L2 carrier frequency, A is the signal amplitude, d is the navigation data, f_{IF} is the IF carrier frequency, $\theta_{n_{i_l}}$ is the accumulated clock noise at time t_{i_l} (it is composed of the total phase and frequency clock disturbances), n is a white Gaussian noise (WGN), C_{M0} is a chip by chip combination of the CM code and zeros, and C_{0L} is a chip by chip combination of zeros and the CL code, f_d is the Doppler shift, t_{i_l} is the time of the received samples in the i^{th} interval, $l = 0,\ldots, L_i-1$, where L_i is the number of samples in the i^{th} interval.

Additional signal generator models to obtain the local CM and CL signals, as well as to correlation between the received and the local CM signals can be found in Ziedan (2005).

3. METHODOLOGY

This study used the first 3 modernized GPS satellites transmitting the new civilian L2Csignal: satellites PRN 17, 31 and 12. The launching of satellite PRN 12 in 2006 has provided for the first time an overlapping time of two L2C signals, in alternate periods, between PRN 12 and 17 satellites and between PRN 12 and 31 satellites, respectively, resulting in simultaneous observations. The current work presents an analysis of this new signal focusing on multipath and noise. Data was collected in consecutive days over a very short baseline (2.476 meters). Both ends of the baseline were simultaneously occupied by two ProPak-3 NovAtel receivers. The occupation time varied between 1 to 4 hours depending on satellite's availability and the station coordinates at both ends of the baseline are known with high precision. The daily repeatability of these signals has been investigated aiming at extracting and to separating the receiver multipath and noise (Farret, 2000). The experiment scenario was the roof of Gillin Hall building at the University of New Brunswick, Canada. We consider the main multipath source in the experiment scenario a 3 meters high wall from approximately 5 meters from the receiver antennas.

1.1 The residual code double differences

The basic observable used for the investigation presented in this paper is the pseudorange multipath and noise residual double-difference $\nabla\Delta\varepsilon^{1i}_{mult12(k)}$ at epoch *k*, that was extracted using the L2C code pseudorange measurements. This observable follows from the equation presented by Xia and Liu (2001), generalized as:

$$\begin{aligned} \nabla\Delta\varepsilon^{1i}_{mult12(k)} &= \nabla\Delta\Gamma_{1i(k)} + \nabla\Delta N_{1i} \\ &- a^{1i}{}_{12(k)}\hat{x} - b^{1i}{}_{12(k)}\hat{y} - c^{1i}{}_{12(k)}\hat{z} \\ &= DD_{observed} - DD_{calculated} \end{aligned} \quad (2)$$

In the original equation by Xia and Liu (2001), the term $\nabla\Delta\Gamma_{1i(k)}$ represents the double difference carrier phase and $\nabla\Delta N_{1i}$ the double difference integer carrier phase ambiguity. In our study, $\nabla\Delta\Gamma_{1i(k)}$ represents the double difference pseudorange and $\nabla\Delta N_{1i}$ does not exist. The other terms, $a^{1i}{}_{12(k)}$, $b^{1i}{}_{12(k)}$ and $c^{1i}{}_{12(k)}$, are the double difference baseline components, $\hat{x}$, $\hat{y}$ and $\hat{z}$ are the station coordinate estimates, $DD_{observed}$ represent the double differenced pseudorange observations and $DD_{calculated}$ the double differenced geometric distance. Further models and detailed explanation on the multipath and noise from residual code and phase DDs and on DD GPS measurements can be found in Xia and Liu (2001) and Guo (2005). This equation is simplified since, due to the very short baseline length, there are no atmospheric errors and the orbital errors are negligible (even more since final IGS orbit products were used). After obtaining the multipath and noise from residual code DDs we figure the statistic to multipath signals as well as the high multipath spatial correlation through the daily sidereal spatial repeatability. All the routines and plots were coded using Matlab tools.

4. RESULTS

Figures 1 to 6 show the multipath and noise signal extracted from the code pseudorange double differences between satellites PRN 12 and 17 in the 3 survey days. Figures 1 to 3 show the signal extracted from L2C and Figures 4 to 6 shows the signal extracted from L1-C/A. It is possible to verify the high similarity among plots 1 to 3 and 4 to 6. We consider that the repeated portion of the signal is only multipath, the remnant being noise. In the cases shown in the plots the L2C Pseudorange Double Differenced standard deviation is nearly 1.1 centimeter. The maximum L2C multipath amplitude varies from 5 meters (Figure 2) to 6 meters (Figures 1 and 3). It is lower than the L1-C/A multipath maximum amplitude which is more than 7 meters in all cases as shown in Figures 4, 5 and 6. This result was expected because of the better performance of the L2C signal, consequence of its low noise, especially to track the peak of the correlation function. We hope that this better performance will happen in indoor environments even if under smaller received signal power conditions, better than the L1-C/A, for example. Fontana et. al. (2001) shows more detailed comparisons between L2C, L1-C/A and L5 in terms of total power, channel power and relative signal performance.

Figura 1 – L2C multipath and noise from residual code DDs between PRNs 12 and 17, first survey day.

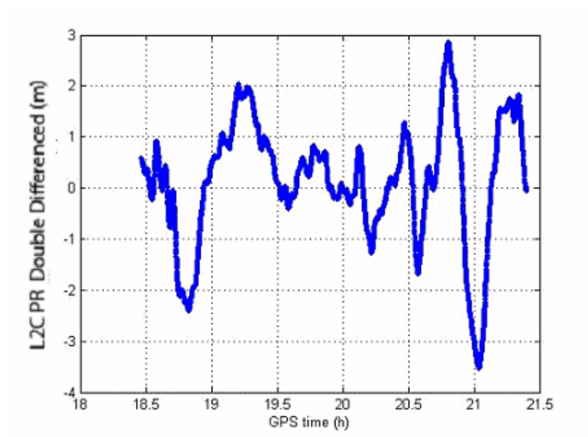


Figure 2 – L2C multipath and noise from residual code DDs between PRNs 12 and 17, second survey day.

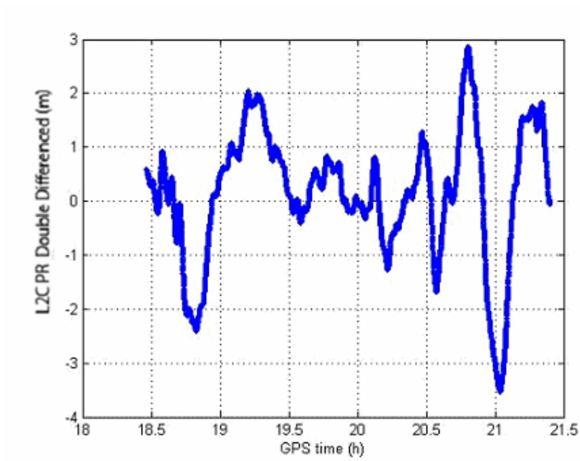
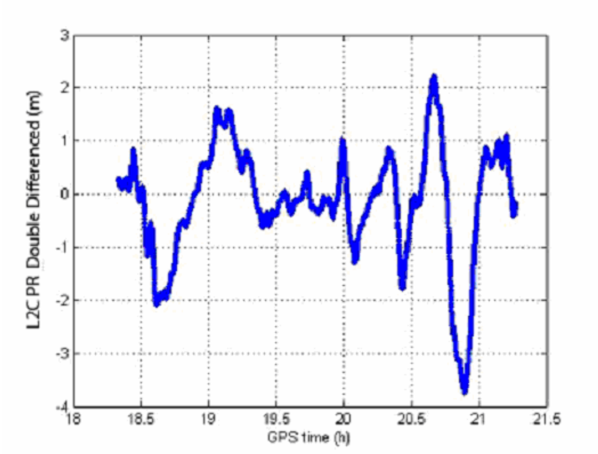


Figure 3 – L2C multipath and noise from residual code DDs between PRNs 12 and 17, third survey day.



In the following Figures 4, 5 and 6 we can see the poor performance of the L1-C/A signal in terms of noise and multipath, which is evident especially in the high frequency terms, in comparison with Figures 1, 2 and 3.

Figure 4 – L1-C/A multipath and noise from residual code DDs between the PRNs 12 and 17, first survey day.

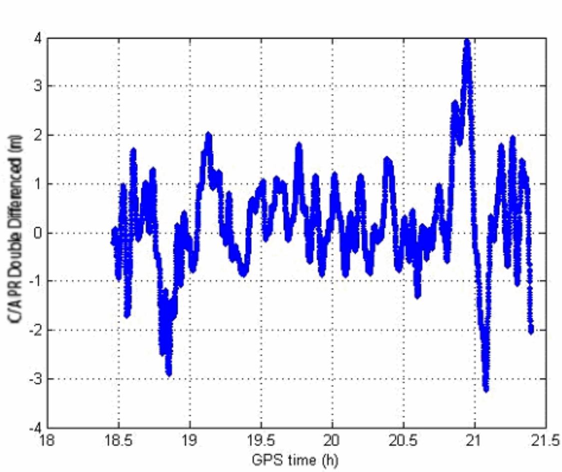


Figure 5 – L1-C/A multipath and noise from residual code DDs between the PRNs 12 and 17, second survey day.

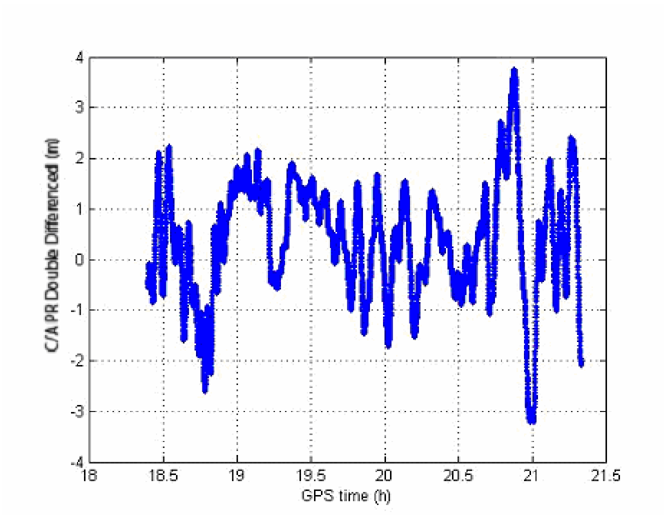
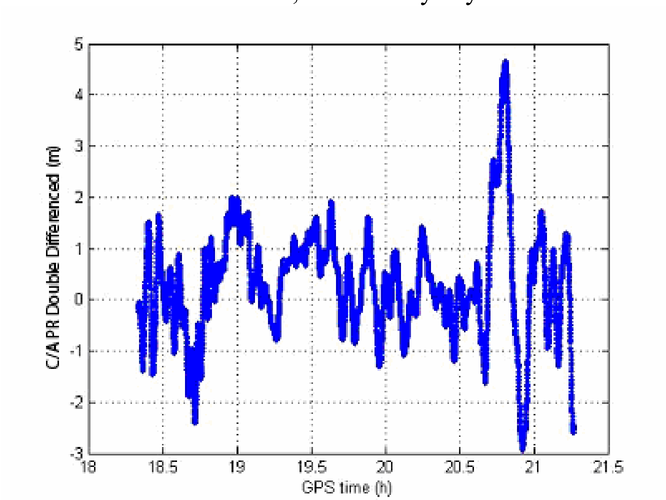


Figure 6 – L1-C/A multipath and noise from residual code DDs between the PRNs 12 and 17, third survey day.



The daily repeatability is a representative feature of multipath. We calculated the correlation coefficient for both L2C and L1-C/A code multipath and noise between the first and the second days, between the second and the third days and between the first and the third day. These values are from the Pseudorange Double Differenced Covariance Matrix. The results are shown in the Table 1, in percentage.

Table 1 – Multipath daily repeatability (%).

	Days 1/2	Days 2/3	Days 1/3
L2C	*88.34*	*93.18*	*96.26*
L1 – C/A	*83.50*	*90.21*	*87.58*

Table 2 indicates the noise, defined as whatever multipath is left from 100% . The results indicate that the L2C signal has smaller noise values than the L1-C/A. This heuristic statement is justified because the portion of the signal that is not repeated is noise.

Table 2 – Noise daily variation (%).

	Days 1/2	Days 2/3	Days 1/3
L2C	*11.66*	*6.82*	*3.74*
L1-C/A	*16.50*	*9.79*	*12.42*

If we consider a value of 6.7 meters as L2C mean multipath plus noise maximum amplitude error and a value of 8 meters as L1-C/A mean multipath plus noise maximum amplitude error and considering also the mean daily repeatability (92.6% for L2C and 87.1% for L1-C/A) we can consider the following values of multipath and noise errors separately, as indicated in Table 3.

Table 3 – L2C and L1-C/A multipath and noise errors.

	Multipath (m)	Noise (m)
L2C	*6.20*	*0.80*
L1-C/A	*6.97*	*1.03*

Besides distance error in the pseudorange, the noise can bring about other issues. One of them is the time measure instability from the receiver clock. Figure 7 shows the noise effect on the time jump between the RINEX data files from the first and the second surveys. The theoretical time difference value would have to be 3 minutes and 56 seconds (or 236 sec), as indicated in Figure 8. But it can be observed in Figure 7 that, in spite of the mean being around 3 minutes and 56 seconds, the time difference is not exactly that value in several occasions. Additional information on the L2C code tracking accuracy can be found in Fontana et. al. (2001).

Figure 7 – Observed daily difference in sidereal time between the first and second survey days (sec).

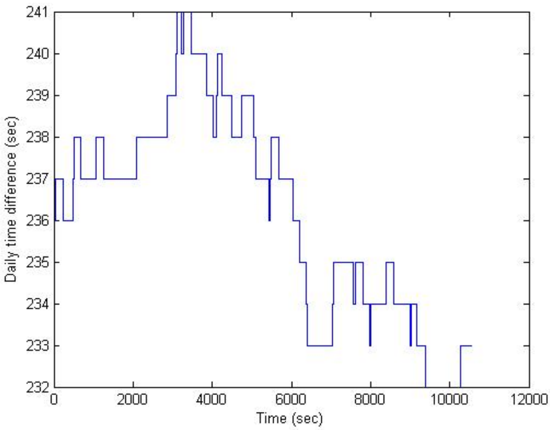
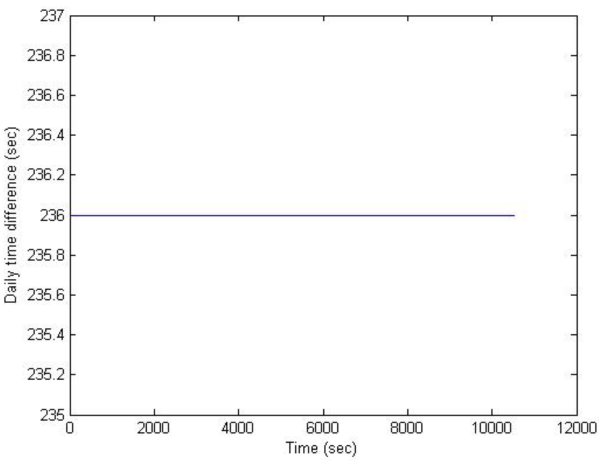


Figure 8 – Theoretical daily difference in sidereal time between the first and second survey days (sec).



5. CONCLUSIONS AND FUTURE WORK

The results described in this paper confirm the best behaviour of L2C than L1-C/A under multipath and noise conditions. This best behaviour results in a better correlation function peak detection and better pseudorange and phase estimates.

This fact plus a lower level power requirement to the initial acquisition and satellites tracking brings a promising future to the L2C signal especially in applications under challenging environments such as cell phones and urban area surveys. In other less challenging applications, e.g., post-processing estimates requiring longer session, a processing signal tool can be used to identify and remove a certain amount of multipath.

Similar study by Simsky et. al. (2006), shows results between L2C and C/A pseudorange noise and multipath obtained directly from SNR receiver measurements under a internal multipath mitigation algorithm. In this study a single satellite transmiting L2C signal was used, resulting in a sub-optimal separation of noise and multipath.

We have shown in a rather heuristic fashion that multipath and noise dominate L1-C/A in a stronger way than in the L2C signal. Also, we detected a difference in the sidereal time, which may be a consequence of noise. Among remaining questions, one relates to whether there is any degree of difficulty for the receiver to handle the new kind of modulation which is so different from that of the existing signals.

For future works we will concentrate efforts to separate in a more accurately way the multipath and noise. To achieve this we intend to make use of SNR measurements (Reichert & Axelrad, 1999), the calibration using the geometry around the antenna and zero baseline (Kee & Parkinson, 1994), harmonic functions (Amiri-Simkooei, 2005) and a better analysis on DD GPS measurement systematic errors (Guo, 2005).

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